

METHOD AND APPARATUS FOR THE DETECTION OF OBJECTS USING ELECTROMAGNETIC WAVE ATTENUATION PATTERNS

BACKGROUND OF THE INVENTION

5 Radar was developed in World War II to detect enemy aircraft. It has subsequently been refined to detect a large variety of objects, including ships, helicopters, satellites, and land vehicles. Radar systems typically work on the principle of bouncing microwave radiation off an object and analyzing the reflected signal (echo). The reflected signal can be used to develop information about the object, e.g., by measuring the round trip signal (echo) time the distance to
10 the object can be determined, and by determining a Doppler shift of the echo a velocity of the object may be estimated. With sophisticated system design, object shape and size may be analyzed. Finally, a temporal analysis of sequential echoes may be used to detect a motion vector and characteristics of moving parts of the object.

15 Radar systems thus emit an electromagnetic wave or pulse, and analyze a reflection pattern to determine a characteristic of the object, distinguishing the object from clutter and background based on a return time of the echo. Radar is typically employed to determine an object profile, or shape, distance (range) and/or its velocity.

20 Electromagnetic detection techniques have developed to include radio frequency and microwave Radar, laser Radar (Lidar), FLIR (forward looking infrared), fluorescence techniques (especially to detect jet engine combustion emissions) and visual techniques.

25 Once Radar saw widespread use, military planners saw the military advantage that would accrue from having craft that are invisible to Radar. After decades of research and development, the United States began deployment of so called stealth aircraft in the 1980's. The next generation of helicopters, ships and missiles are also designed to be "stealthy". Any craft can be designed to be stealthy, including land craft and satellites. The design principles of stealth aircraft are principally to (a) reduce radar reflections, especially retroreflections, of all kinds, and (b) to particularly hide or reduce characteristic signatures of aircraft, such as signals produced by engine turbine blades and wing surfaces.

30 The primary method for making an object stealthy is to reduce its radar cross section. While much of the performance of stealth aircraft is classified, it has been claimed a stealth fighter has the radar cross section of a normal plane the size of a bird, i.e., that it reflects no more microwave energy back to the detection device than a non-stealth plane the size of a bird.

35 There are several techniques, applied together, that are used to effect stealth. One is to design the craft so that flat surfaces are divided into small areas of various inclinations, disposed to avoid reflecting the signal directly back to the receiver. The craft is designed such that exposed surfaces present oblique angles or rounded surfaces that scatter or diffuse the signal away from the source of the radar beam. In addition, surfaces are coated with materials that

absorb microwave radiation, and honeycomb sections are formed which trap microwaves, preventing reflections. See, U.S. Patent Nos. 5,808,577, 5,697,394, 5,694,763, 5,536,910, 5,420,588, 5,276,477, 5,036,323, 4,606,848, 4,173,018, 4,117,485, 4,030,098, 4,019,699, expressly incorporated herein by reference.

5 The United States no longer has a monopoly on stealth craft. After the efficacy of stealth was proved during the Persian Gulf War, Germany, Russia, South Africa and other developed countries accelerated their development of stealth craft, and now not only have stealth craft for their own use, but are poised to sell stealth craft to developing countries, some of which are hostile to the United States.

10 Therefore, it is becoming increasing important for any military to be able to detect stealth craft.

15 The existing methods for detection of stealth aircraft include thermal signatures, exhaust signatures, acoustic signatures (see, U.S. Patent No. 4,811,308, expressly incorporated herein by reference), radar employing non-traditional wavelengths (see, U.S. Patent Nos. 5,850,285, and 5,657,022, expressly incorporated herein by reference), satellite imagery, and analysis of radio frequency emissions from the aircraft. However, none of these methods replaces traditional Radar monitoring.

20 U.S. Patent No. 5,990,822 (Honigsbaum, Nov. 23, 1999), expressly incorporated herein by reference, describes a system for detecting stealthcraft based on silhouette methods, e.g., where the receiver aperture is aligned with an outgoing transmitted beam. Distance to an object is estimated by triangulation and sequence of beam returns.

SUMMARY OF THE INVENTION

The present invention therefore provides a method and apparatus for the detection of objects, e.g., all craft types, regardless of whether they are designed to have a low radar profile or not, and thus including both stealth craft as well as non-stealth craft. In particular, it is sought to
5 detect airplanes, Intercontinental Ballistic Missiles (ICBM), helicopters, satellites, cruise missiles, pilotless drones, balloons, High Altitude Long Endurance (HALE) platforms (which are robotically piloted dirigibles or winged craft), ships, boats, submarines, tanks, trucks, armored personnel carriers, and cars.

The present invention operates by detecting, not the echo of an electromagnetic wave
10 reflecting off an object, but rather an attenuation of an electromagnetic wave pattern due to obstruction of beam propagation by the object. Therefore, design principles of stealth craft which seek to absorb microwave radiation will increase contrast, making them "visible".

While beam interruption sensors are well known and used in security systems and industrially, the present system includes a number of distinctions. The system according to the
15 present invention does not seek to provide a narrow beam that is fully blocked by the object to be detected. Rather, at the typical region of intersection between the beam and the craft, the beam illuminates a much larger area than the cross section of the craft. The present invention, in fact, seeks a wide area of coverage, and therefore provides a region of detection significantly larger than a "line of sight". It is noted that, in traditional systems, detection is limited to "line of
20 sight", possibly with predetermined reflections of the beam, and off axis sensitivity is extremely limited by design. Thus, according to the present invention, a large volume of space may be monitored by a detector node, similar to traditional Radar installations and in contrast to known shadow detectors.

Video detectors are also known. These detectors monitor pixels of an imaging sensor for
25 illumination changes, which may be due to shadowing of a background. These systems, however, are limited to certain electromagnetic bands, for example mid- or near infrared to X-ray ranges. As such, these systems are only employed in limited range applications, since beam propagation may be limited by atmospheric conditions or noise, and typically are difficult to accurately detect over long distances through the atmosphere. In contrast, the present invention
30 employs a long range detection system, for example having a detection range of at least several miles, and detection over a large volume, for example at least several cubic miles.

The principal of the Negative Radar can best be explained in terms of an analogy. Suppose an airplane was coated with a surface that absorbed all visible light, thus reflecting no
light. If, during the night, you aimed a search light at the airplane, you would not see any
35 reflected light, making the plane not visible, thus effectively invisible. However, if you observed

the same airplane flying the next day against a blue sky, you could see the silhouette of the airplane.

Similarly, the present invention provides a method and apparatus for detecting an alteration in a background radiation pattern resulting from an object interfering with transmission thereof.

In order to be effective, the electromagnetic wave path between the region to be monitored and the receiver must have a set of convergent wave paths. Typically, this is effected by providing an intermediate scattering of the electromagnetic beam. While this intermediate scattering reduces beam power efficiency as compared to a substantial retroreflection, in typical applications thus reduction in sensitivity is compensated by an increase in output power, or the use of an existing high power irradiation source.

It is noted that one method for defeating the detection method and apparatus according to present invention is to emit a radiation pattern from the object corresponding to a presumed or measured background pattern, in order to avoid detection. In order for such a system to also defeat detection by normal Radar and radio frequency emission monitoring methods, a phased array antenna must accurately detect the incident illumination pattern and a phased array antenna on an opposing craft surface must retransmit the corresponding pattern, wherein the phased array antennas must encompass an area on each face of the craft (e.g., top, bottom, sides, front and rear) and must be themselves "stealth" designs. Such an anti-detection system is therefore another aspect of the present invention. See, U.S. Patent No. 4,684,952, expressly incorporated herein by reference.

In one embodiment of the invention, specific artificial sources of radar emissions are deployed and/or employed to specifically define a pattern to be interrupted by the craft to be detected. It is noted that typical stealth designs make presumptions regarding the angle between the emitted Radar wave for detection and the receiver, i.e., that these are close or identical. Therefore, a particular design principle of stealth craft is to avoid any direct reflections or retroreflections of microwave energy. These presumptions fail where the angle is substantially different from zero, for example the limit case of obscurity of a microwave source. However, these methods also fail under other circumstances.

As used herein, the phrase Negative Radar refers to the effect wherein the silhouette of any craft, including a stealth craft, will block transmission of a Radar beam, resulting in detectability of the attenuation of the microwave radiation. The Negative Radar approach can be used with active or passive detection techniques.

In an active detection technique, electromagnetic energy, such as radio frequency, microwave, visible light, or infrared light (from a laser) is directed toward a target, and the interaction of the emitted energy with the target is used to detect the presence of the target, and to

derive characteristics of the target, such as distance, bearing, speed, size, and profile. According to the present invention, the beam transmission characteristics are used for detection, rather than reflection characteristics.

In an active detection scheme according to the present invention for Negative Radar, an electromagnetic wave is bounced off a large reflector, such as the Earth, and the silhouette (or attenuation of the electromagnetic wave) produced by the craft, by blocking part of the wave or part of the reflection of the wave, is detected.

In a passive detection embodiment of the invention, no energy is intentionally directed toward the target. Instead, natural or preexisting (and relatively uncontrolled) sources of electromagnetic radiation are employed to look for the silhouette (or attenuation of the beam) of the craft. Typically, the passive detection techniques will employ background radiation from the sky (e.g., 3 degree K black body radiation), or the infrared energy emitted by the Earth (e.g., 300 degree K black body radiation). Another useful source of "passive" energy is man-made satellites, for example GPS satellites and the Iridium satellite constellation, which each have almost complete coverage of the globe and well defined radiation characteristics.

It is therefore an object of the invention to provide a method for the remote detection of an object within a large space, comprising detecting a normal pattern of illumination of the space with electromagnetic radiation, allowing the object to enter the space, and detecting an attenuation from the normal pattern resulting therefrom. In this case, the space is substantially larger than the object, and the aperture of the receiver is wide.

It is also an object of the invention to provide a method of operating a negative radar device for detecting objects, e.g., stealth craft or non-stealth craft, herein called "Stealth Craft", comprising the steps of either detecting the absence of microwave radiation, or both transmitting microwave radiation and detecting the absence of microwave radiation, due to the stealth craft attenuating (blocking) the microwave radiation when it positioned between the source of microwave radiation (or a reflection from the source) and the microwave detector or receiver (or surface that reflects microwave to the detector or receiver).

It is a further object of the invention to provide a method and apparatus for detecting an object, comprising the steps of defining expected characteristics of a scattered invisible electromagnetic radiation pattern to be detected at a receiver, attenuating at least a portion of an invisible electromagnetic radiation field by a presence of an object within a path of invisible electromagnetic radiation, said invisible electromagnetic radiation propagating off axis with respect to the receiver toward a scattering medium, and detecting the attenuation to indicate a presence of the object. The electromagnetic radiation may be man made or natural, and therefore sources such as earth (terrestrial) background radiation in the infrared band and cosmic background radiation in the microwave bands may advantageously be employed. The present

invention may also use incidental effects from man-made radiation transmitted for unrelated purposes, or cooperating transmitters and receivers. The transmitter and/or receiver may be highly directional (collimated), in order to provide precision in localization or higher signal to noise ratio. Antenna apertures may be mechanically scanned, or comprise synthetic aperture systems with logically defined apertures. Adaptive background analysis techniques may be performed to differentiate dynamic effects from static effects.

According to a preferred embodiment of the invention, a receiver is provided displaced (e.g., substantially spaced) from the source of the electromagnetic radiation, wherein the perturbation in the electromagnetic radiation is detected as a displaced shadow on a distant scattering medium, such as the earth, or overhead, such as clouds or atmospheric particulates. The present invention also provides a system and method wherein a transmitter generates the electromagnetic radiation, a receiver detects the electromagnetic radiation, the transmitter and receiver having known positions with respect to the Earth, with a distance to the object being determined based on the known location of the receiver and the transmitter and by the vector from the receiver to a shadow of the electromagnetic radiation formed by the object on the Earth. Likewise, at least two electromagnetic radiation waves may be generated by at least two transmitters and a receiver, each with a known position, wherein a distance to the object is determined based on the known location of the receiver and both transmitters and by the vector from the receiver to the shadow from the first transmitter in geometric relationship with the vector from the receiver to the shadow from the second transmitter.

The object may be identified based on a computed distance to the object, the detected attenuation of the electromagnetic radiation, and a predetermined characteristic of the object. A system is also provided wherein a wavelength of a radio wave transmission is varied about a range including the effective size of the object, wherein as the wave exceeds the effective size, the objects apparently disappears. By monitoring perturbation (e.g., attenuation) of the silhouette (i.e., transmitted wave propagation axis and receiver aperture aligned) or shadow (i.e., transmitted wave propagation axis and receiver aperture not aligned), the effective size of the object may be determined. Typical objects of interest have sized and effective sizes in the range of between about 1 to 100 meters, and therefore a transceiver system adapted to operate in the 1 to 100 meter band may be used for such detection.

The invention also provides a negative radar device for detecting an object, e.g., stealth craft or non-stealth craft, comprising either a microwave receiver and optionally a microwave transmitter, said detector detecting the absence or attenuation of microwave radiation due to attenuation of the microwave radiation when the object is within the aperture of the receiver, e.g., generally positioned between the transmitter or other source of microwave radiation (or a

reflection from the transmitter or other source) and the microwave receiver (or surface that reflects microwave to the detector).

Microwave, as generally used herein, may also encompass any electromagnetic radiation capable of attenuation by the object, unless specifically limited by the context. The object may be, e.g., any type of craft, e.g., airplanes, Intercontinental Ballistic Missiles (ICBM), helicopters, satellites, cruise missiles, pilotless drones, balloons, High Altitude Long Endurance (HALE) platforms, marine ships, boats, submarines, tanks, trucks, armored personnel carriers, and cars.

The microwave radiation may be, for example, the omnipresent cosmic background radiation, the blackbody radiation from the Earth, microwave radiation reflected from the ground or sky. The system may provide a single microwave transceiver for emitting and receiving the microwaves, or the transmitter and receiver may be spatially separated.

In order to collimate the microwaves for detection of small areas within the detection space, tubes may be used to limit the field of view that is seen by each detector, thus increasing the percentage attenuation caused by a Stealth Craft in that pixel of the Sky.

The aperture of a transmitter or/or receiver may be limited, to provide one or more narrow bands of electromagnetic radiation or apertures for receipt of radiation, in the form of a "picket fence". These bands may be static or swept. For example, the receiver may be omnidirectional, while the transmitter sweeps the sky with bands of directional radiation. Alternately, the transmitter may be omnidirectional, while the receiver may sweep the "sky" with bands of directional "beam" sensitivity, through the use of a moving mechanical antenna or a phased array radar system.

The distance to an object, e.g., a stealth craft, may be determined from the known location of both receiver and transmitter and by the vector from the receiver to the shadow of the stealth craft on the Earth in geometric relationship to the vector from the receiver to the silhouette of the stealth craft against the Earth.

According to another embodiment, there are at least two transmitters and at least one receiver, or there are at least two receivers. For example, two transmitters are provided, and the distance to the stealth craft is determined from the known location of the receiver and both transmitters, and by the vector from the receiver to the shadow from the first transmitter in geometric relationship with the vector from the receiver to the shadow from the second transmitter.

The transmitter need not be controlled or coupled to the detection system. For example, the transmitter may be a non-cooperating source of microwave radiation, such as a Direct Broadcast TV satellite, geopositioning (e.g., GPS or GLONASS) satellite, or a personal communication satellite. Therefore, the system need only provide a receiver and phased array antenna to detect and/or determine the distance to Stealth Craft.

In analyzing the received signal, an adaptive receiver design may be employed to cancel the normal illumination pattern. In this case, the background normally reflects or scatters the radiation. However, an obscuring object reduces the return signal. When compared with the adapted baseline signal, however, the silhouette and shadow of the stealth craft is seen as a positive indication of change in pattern.

The distance to the object, e.g., stealth craft, may be determined by comparing the apparent size of the stealth craft to a presumed actual size of the stealth craft, using geometrical techniques well known in the art.

These and other objects will be apparent from an understanding of the preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

These and further objects and advantages of the invention will be more apparent upon reference to the following specification, claims and appended drawings wherein:

Fig. 1 shows a perspective view of a set of Electronic "Picket Fences";

Fig. 2 shows a perspective view of a system for detecting Stealth Craft with a single transmitter/receiver;

Fig. 3 shows a perspective view of a system for detecting a distance to a Stealth Craft by triangulation;

Fig. 4 shows a block diagram of a system for canceling a wave of known wavelength;

Fig. 5 shows a Table representing background cancellation and leading and trailing edge detection;

Fig. 6 shows a Table representing background cancellation and making a silhouette "white";

Fig. 7 shows a Table representing background cancellation and making a shadow "white";

Fig. 8 shows a perspective view of a system for detecting stealth craft with omnidirectional transmitter and separate receiver;

Fig. 9 shows a perspective view of a system for detection and distance determination with two transmitters and a separate receiver using shadows;

Fig. 10 shows a perspective view of a system for detection and distance determination with one transmitter and a separate receiver using both silhouette and shadow;

Fig. 11 shows a perspective view of a system for detecting stealth craft using the Earth's atmosphere to reflect radiation;

Fig. 12 shows a perspective view of a system for detecting stealth craft using cosmic background radiation; and

Fig. 13 shows a perspective view of a system for determining distance with cosmic background radiation.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The preferred embodiments will now be described by way of example, in which like reference numerals indicate like elements.

5 Active Detection

In standard active detection, a beam of electromagnetic energy, such as microwave, visible light, or infrared light (from a laser) is directed toward a target and the energy reflected from the target is used to detect the presence of the target, and to derive characteristics of the target, such as distance, bearing, speed, and size.

10 However, according to the present invention, negative radar, a microwave beam is bounced off a large reflector, such as the Earth, and the silhouette (or attenuation of the microwave) that the object produces against the beam or a reflection of the beam is detected. This method can also be used with non-stealth craft, since the Doppler shift of microwaves reflected from a non-stealth craft can be used to differentiate it from the microwave reflected from, e.g., the Earth, so that the microwaves reflected directly from the non-stealth craft can be ignored or separately analyzed.

15 The Doppler shift can also be used to detect and defeat a possible electronic countermeasure against negative radar. If a stealth craft emanated microwave radiation in an attempt appear transparent to the rays, e.g., not to produce a "silhouette" for the negative radar, the Doppler shift could be used to differentiate the microwave emanated from the stealth craft from the microwave reflected from, e.g., the Earth. Therefore, a successful countermeasure would not only have to emit radiation in the appropriate pattern, it would also have to be Doppler compensated. This would require, for example, a complex phased array transceiver system which measures electromagnetic radiation on any one surface and reemits it on an opposite surface, potentially requiring simultaneous transmission and reception in the same range or frequencies from all surfaces.

20 The following is an example of Negative Radar and active (as opposed to passive) detection. An aircraft, HALE craft, or satellite is provided at an altitude above that of the craft to be detected. A down-looking beam of electromagnetic energy is swept across the ground. The beam, in this case, could be infrared light (via a laser), microwave (with the beam steered either mechanically or electronically with a phased array antenna), or some other electromagnetic radiation, although microwave radiation is preferred. It is presumed that the ground below scatters the radiation, and therefore, the illuminated area will be substantially visible to the receiver.

25 For example, an aircraft is provided having a phased array Radar antenna, to allow for a full sweep of the entire zone of interest. As shown in Fig. 1, the aircraft 100a scans the area with

a set of narrow spaced beams, creating a series of electronic "picket fences", 101a, 101b ... 101n. Each "picket fence" is thus a sweep of a plurality of individual beams. A particular advantage of this arrangement is that the entire zone is effectively covered over time with only a relatively small area of microwave illumination, and each "picket" may be individually analyzed, for example with different wavelengths and/or parameters.

When a Stealth Craft 102S crosses an individual beam, the strength of the beam reflected from the ground is attenuated, because the Stealth Craft blocks a portion of the beam coming from the craft to ground, as well as part of the reflection of the beam from ground back to the aircraft. Therefore, in this case, it is possible to visualize the Stealth Craft as a "dark" area against the "white" background of Microwave reflected from the ground. This analysis, of course, preferably automated, and may involve high levels of analysis, for example to reduce noise, check consistency with other sensor systems, and adaptively process the signal. Typically, a background or normal radiation pattern from the ground is determined, and the received radiation compared with the background to determine the characteristics of the reflected components.

As shown in Fig. 2, when a Stealth Craft is detected, we know that the Stealth Craft 110c is in the line-of-site between the source (aircraft Radar) 110a of beam 110b and the ground. Since we know where the beam is sweeping at any point in time, we know the Z position of the Stealth Craft, but not the Y position (altitude) and thus not the distance to the Stealth Craft.

One way to find the distance to the Stealth Craft is a method of triangulation, as shown in Fig. 3. We assume a plurality of detecting craft creating picket fences via sweeping beams 115e and 115f. If a second detecting craft detects the Stealth Craft at time T, we know not only the 115a -115b path from the first detecting craft to the target craft, but the path 115c - 115b from the second detecting craft to the Stealth Craft.

Since we know the absolute position of the two detecting craft, e.g., by the use of GPS, and we know the angle of the Stealth Craft relative to the two detecting craft, and we know the Z position of the Stealth Craft, we can form a triangle, and calculate, using basic geometry, the X, Y, Z position of the Stealth Craft, and thus the distance from each Radar to the Stealth Craft. The accuracy of the distance determination depends upon, for example, the width of the individual beams.

If only one Radar is used, the traditional way to determine the distance to a non-stealth Craft is to measure the time that it takes to receive the Microwave echo from the craft. Since the speed of Microwave in the air is known, about 300,000 KM/second, the distance to the craft may be determined. With a Stealth Craft, the echo from the craft is presumed unusable, so the distance to the Stealth Craft must be determined by other means.

One way to determine the distance is to compare the apparent size of the Stealth Craft to the actual size of the Stealth Craft, using geometrical techniques well known in the art and presumptions of the nature of the Stealth Craft. The apparent size is the size of the silhouette. The actual size can thus be determined by reading a computer reference file for the aircraft dimensions of the particular Stealth Craft suspected of detection. Ambiguities may be resolved by other data, such as maximum velocity, and radar signature characteristics. It is noted that traditional Radar is ineffective in detecting the presence of a Stealth Craft because of the large number of possible interfering signal sources and noise. On the other hand, where a specific position of a craft is suspected, numerous techniques may be employed to verify the existence of the craft.

Another way to find the actual size of the Stealth Craft is by increasing the wavelength of the Microwave until the silhouette disappears, i.e., until the size of the craft (cross-section) becomes a fraction of the wavelength, so that the Stealth Craft does not effectively attenuate the Microwave signal and thus becomes "invisible" to the Microwave.

The azimuth resolution, i.e., the minimum size of a feature you can detect, is dependent on the size of the antenna, the distance from the Radar to the object, and the wavelength, and is given by:

$$\text{Resolution} = (\text{Wavelength} * \text{Range}) / \text{antenna length}$$

$$\text{Wavelength} = (\text{Resolution} * \text{Antenna length}) / \text{range}$$

Thus, for a given antenna size, range and desired resolution, the wavelength needed to effect the needed resolution is defined, e.g.,

$$\text{Wavelength} = (1 \text{ m} * 20\text{m}) / 10,000 \text{ m}$$

$$\begin{aligned} \text{Wavelength} &= .002 \text{ m} \\ &= 2 \text{ mm} \end{aligned}$$

The aforementioned distance measurement techniques would also work for non-stealth craft, since the Doppler shift of microwaves reflected from the non-stealth craft could be used to differentiate it from microwave reflected from the ground, so that the microwaves reflected from the craft could be ignored. Thus, by providing a filter to detect microwaves shifted by an amount representing a minimum presumed velocity of an aircraft, background clutter may be effectively eliminated.

Active downlooking Radar will show clutter, i.e., reflection from the ground. The varying characteristics of the surface of the ground and items on the surface will result in a varying amount of reflected microwave signal from the ground.

This ground clutter can be eliminated by the use of cancellation, a technique well known in the art. Fig. 4 shows a simplified block diagram of the method. The received signal 120a from the antenna is split (bifurcated) with half going through a delay 120b, and then recombined.

This delay is equal to, for example, a half-wavelength phase delay. Thus, if the reflected microwave signal is stationary, i.e., at time t is exactly the same in terms of amplitude and phase as the signal at time $t - 1$ delay, then the signal is cancelled, because the two components are 180 degrees out of phase, and there is no substantial output 120c. The delay can also be any odd multiple of $\pi/2$ phase delay. It is understood that this cancellation technique may be provided in known manner by advanced analog or digital electronic systems, and therefore need not be provided as a simple delay line summer.

As shown in Fig. 5, as the Stealth Craft transverses the detection zone, the clutter cancellation will make the ground "dark", i.e., all microwaves from the ground will be cancelled. The Stealth Craft will, itself, reflect no microwave, so that it will also be "dark".

However, the delay is selected such that as the Stealth Craft transverses the detection zone, the edge of the Stealth Craft will be shown as a "white" edge, i.e., all microwave energy reflected will be cancelled, except that at the edge of the craft. As shown in Fig. 5 the microwave at the leading edge of the craft will not be cancelled because the current signal reflected from the ground is blocked but the previous (delayed) reflected signal from the ground was not blocked by the craft so it is not cancelled by the current signal.

Thus, the leading and trailing edges of the craft will be the only areas where the microwave will not be either blocked or cancelled. While this technique is subject to noise limitations, the precision may be improved by correlating leading and trailing edge detections, which should be spaced in time according to the size and speed of the craft. The transverse distance the Stealth Craft moves during each pulse determines the "width" of the leading edge of the Stealth Craft. At a speed of 1 KM/sec., the Craft would move 1/300 KM during a 1/300-second pulse interval, thus the leading edge would be about 3.3 meter.

When a Stealth Craft is detected, another option is to freeze the background cancellation, i.e., to cancel with the same (pre-stealth craft detection) background as long as the Stealth Craft is being detected, such as with a analog amplitude adjusted phase lock loop or digital background cancellation. This results in the craft (actually the silhouette of the craft) being entirely "white" (microwave source) as shown in the Fig. 6. The result is similar to the correlation of leading and trailing edges, since noise considerations will make higher level processing for consistency and conformance with reasonable windows desirable.

In addition to detecting the silhouette of a Stealth Craft against a microwave source, another method of detecting a Stealth Craft is to detect the shadow the Stealth Craft makes on a reflecting surface, such as the Earth.

As in detecting a silhouette, the attenuation of the Microwave by the Stealth Craft is to be detected. Thus results in a "dark" area on a "white" (reflecting) surface.

As with detection of a silhouette, background cancellation may be used to cancel the background and make the shadow "white", so that a "white" patch on a "dark" background is sought. In this case, a moving average cancellation technique may be employed, for example with a time constant of about 15 seconds. In this case, as a Stealth Craft enters the aperture, the change against the background will be apparent, yet changes in the background over a slower time-course will be compensated. Alternately, an adaptive cancellation system may be implemented, which may, for example, halt adaptation during the period of detection of an event, to provide maximum "contrast" of the event. Other, more complex filtering algorithms may also be employed. In any case, as a Stealth Craft is being detected, then the shadow of the stealth craft becomes "white" (microwave source) and the non-shadow background becomes "dark" (no microwave) as shown in Fig. 7.

As discussed above, the negative Radar technique works for non-stealth craft, as well as for stealth craft. This is important because it may not be determined, a priori, if a craft being detected is a stealth craft or non-stealth craft, and thus a single detection system, compatible with both types of craft, may be desired.

An electronic picket fence can be established such that the craft transmitting the microwave is a satellite, high-flying aircraft, or High Altitude Long Endurance (HALE) craft and the receiver is on a second craft that is passively receiving the microwaves, without itself transmitting any microwave signal. The transmitter could be, for example, a phased array Radar sweeping a beam, creating a series of electronic picket fences.

As shown in Fig. 8, in constructing electronic picket fences, the transmitter 130a can be omni-directional, i.e., the transmitter could transmit in all directions, with the receiver 130b being a phased array antenna creating sweeping "beams", one beam 130e of which could detect Stealth Craft 130c. For example, one transmitter on a satellite, aircraft, or High Altitude Long Endurance (HALE) craft could be used by a plurality of receivers to construct a plurality of picket fences.

Thus, the detecting craft can itself be a Stealth Craft, and the system operational without transmitting any microwaves that could be used to detect it, or used by, e.g., a radar-seeking missile (such as HARM), to destroy it.

A satellite used to illuminate the object need not be a cooperating satellite. There are many commercial, government, and military satellites in orbit. For example, a direct broadcast TV satellite or a geopositioning (e.g., GPS or GLONASS) satellite could be used, without the cooperation of the satellite owner, as long as the microwave carrier wavelength and ground coverage are appropriate. Stability and predictability of the carrier may also be important. As of 1998, there were 220 communication satellites in orbit. Between 1998 and 2003, this is expected to grow to over 1000 satellites, with the orbiting of new fleets of satellites for satellite based

cellular telephone service, which are often referred to as personal communication satellites. Some of these satellites will be in low-Earth orbit or mid-Earth orbit, and others will be in geosynchronous orbit.

If two detecting craft detect the Stealth Craft, the distance to the Stealth Craft could be determined by the previously mentioned method of triangulation.

If there is one detecting craft but two or more transmitting sources, as shown in Fig. 9, a different method of triangulation can be used to determine the distance from the detecting craft to the Stealth Craft. The shadow of the Stealth Craft 140s on the ground may be detected, i.e., the area 140e on the ground in which the Microwave beam 140m from the transmitting Craft 140a was partially or fully attenuated or blocked by the Stealth Craft 140S at time T is detected. The area 140f on the ground in which the Microwave beam 140n from the transmitting Craft 140b is partially or fully attenuated or blocked by the same Stealth Craft 140S at the same time T is detected.

The transmitted beams 140m and 140n reflect off the ground, and by use of a phased array receiver, having narrow beam input sensitivity, i.e., directional receiving, with two simultaneous "beams" 140t and 140u, the shadow of the Stealth Craft for beam 140m and the shadow for beam 140n may be detected.

Since the location of transmitters 140a, and 140b, and shadows 140e and 140f, and receiver "beams" 140t and 140u and the receiver 140r are known for the time of receipt, simple geometric techniques, well known in the art, can be used to determine the distance 140d from receiver 140r to Stealth Craft 140s.

If there is only one transmitter and one receiver, and they are spatially separated, yet another method of triangulation can be used to determine the distance to the Stealth Craft. As shown in Fig. 10, for an omni-directional Microwave transmitter 150m, and a receiver 150r, the shadow 150e of the Stealth Craft 150s on the ground, as well as the silhouette 150i of the Stealth Craft 150s against the reflected Microwave at point 150n is detected. Since the various locations of 150m, 150r, 150e and 150n are known for the time of detection, geometric methods, well known in the art, can be used to find the distance from the receiver 150r to the Stealth Craft 150s.

If either standard triangulation or the triangulation methods shown in Figs. 9 or 10 are used in conjunction with non-cooperating satellites, such as geosynchronous Direct Broadcast TV satellites, then controlled active emission sources, e.g., radar transceivers, would not be required to detect and determine the distance to Stealth Craft. All that would be required with these types of sources are a receiver, a phased array antenna, and an appropriate processor. The phased array antenna is controlled to have sensitivity to microwaves in a "band", and possibly multiple simultaneous bands. The frequencies and transmitting characteristics of many satellites are known and published, so shadows and silhouettes at the same frequency of the satellite may

be detected and distinguished. In the case of commercial transmissions, techniques may be necessary to distinguish multiple sources of radiation in the same band. For example, typically, the emission from such satellites will be coherent and modulated. Upon reflection, the radiation will be scattered, because the Earth is an imperfect reflector. However, some coherency as well as the modulation pattern, may be retained. Therefore, a selective filter for the presumed reflected wave may be implemented, filtering out other sources of potentially interfering electromagnetic information. In this case, it is presumed that the Craft to be detected will interfere with the pass filtered wave portion, however, this presumption appears warranted based on the physics of shadow and silhouette formation by a Stealth Craft. Thus, the frequency channel, modulation pattern, and propagation vectors of the satellite transmission may all be used to distinguish from other sources of electromagnetic radiation.

It should be understood that the craft holding the receiver antenna in this case has access to receive a clean representation of the satellite transmission from above, thereby allowing homodyne-type detection and/or the use of phase locked loops.

In an active detection system, there is a transmitted beam and a detected reflected beam. As shown in Fig. 11, instead of a craft directing a beam to reflect off the Earth, the beams 160a, 160b, - 160n, could be directed from the Earth or from a craft via a sweeping or omni-directional transmitter 160t toward the sky, with the microwaves reflected from the sky, to the receiver 160r. The amount of reflection and nature of the reflection depends on the nature of the beams, and the vagaries of atmospheric reflection, such as particulates, ice crystals, and the like. In addition, the atmosphere can absorb energy and re-radiate it.

Passive Detection

In a passive detection system, no energy is intentionally directed to the target. Instead, the silhouette (or attenuation of the microwave) of the Stealth Craft against an existing energy background, such as the cosmic background radiation in the sky, or the infrared energy emitted by the Earth, is detected.

The cosmic background radiation is an omnipresent microwave source, and is the same in any direction up to 1 part in 100,000. The cosmic background radiation is equivalent to the radiation emitted by a black body at 2.7 degrees Kelvin (- 270 Centigrade).

The Earth can also be considered a black body, or a gray body, at the temperature of the Earth's surface. The radiation emitted by a gray body depends on its temperature, its emissivity (determined primarily by its roughness) and its reflectivity.

This background energy is much weaker than that used in typical Radar systems. While an x-band Radar has a typical power (brightness) of 4800 watts/meter squared/Hz/steradian, a typical Earth brightness might be 5.4×10^{-24} , in the same microwave frequency range.

Therefore, specialized receivers called Radiometers are used to measure the brightness of background radiation from thermal sources. A bolometer (or superconducting bolometer) may also be used to detect Earth background radiation.

The background radiation is examined to look for either the silhouette of the Stealth Craft or the attenuation of the background that is caused by the Stealth Craft. The Stealth Craft itself can be considered a gray body, but since it is coated with Microwave absorbing material, it should not reflect much microwave nor should it emit much microwave energy. Thus, passive detection of a Stealth Craft against the cosmic background radiation may be more effective for Stealth Craft than non-Stealth Craft.

In addition to detecting Stealth craft, another advantage of passive Negative Radar over conventional Radar is that the detector can be a device that transmits or emanates no microwave radiation. This makes it much harder for the enemy to find and destroy, with e.g., the use of a microwave seeking missile.

If the weak cosmic background radiation is used, a very sensitive receiver, cooled to close to absolute zero (-273 degrees Centigrade) could be used, which is sensitive to this wavelength of radiation. The Cosmic Background Explorer satellite used differential microwave radiometers to look for anisotropy of 1 part in 100,000 in the cosmic microwave background radiation. The NASA Microwave Anisotropy Probe satellite, to be launched in 2000, will also be able to detect anisotropy of 1 part in 100,000. Therefore, systems that analyze spatial variations in this radiation are well known.

The apparatus according to the present invention will look, at any given time, at a small enough piece of the sky so that a Stealth Craft will cause an attenuation of at least 1/100,000 in the strength of the cosmic background radiation. This will be achieved by insuring that the area (pixel) of the sky being observed at any instance is no more than 100,000 times the size of the Stealth Craft to be detected.

For example, the F117a stealth fighter, with a length 60 feet and height of 12 feet, has a cross section of 720 square feet. Thus, (72,000,000 square feet of sky ($720 * 100,000$) (about three square miles) around the craft (at the distance of the craft) could be observed at any given instance, and the craft would obscure 1/100,000 of the cosmic background radiation. The detection system would therefore compare the strength of microwaves at the time of detection (time X) to a previous time (time X-1) for that pixel.

As shown in Fig. 12, the attenuation of the microwave signal that results from the passage of a Stealth craft 170s in the field of view 170v of a receiver or radiometer 170n is measured.

There are various ways to insure that the area of the sky being observed is no more than 100,000 times the size of a Stealth Craft. For example, if thousands of receivers are used, each

can observe a small pixel of the sky. Alternately, one receiver (radiometer) could be rapidly swept, sequentially sensitive to different small regions (pixels) of the sky.

A cosmic background radiation-based system must be directed away from Earth, and is typically limited to coverage of a radius of 50-100 miles, with a height window of 0.5-20 miles.

5 With a 0.5 square mile pixel area at maximum range, $(2 \times 100 \times \pi \times 20 / 0.5)$ 24,000 pixels would be required. This may be provided, for example, as a rotationally moving scanner with a 64 x 64 array of detector elements, or as multiple stationary arrays each looking in a somewhat different direction.

10 As shown in Fig. 12, if a plurality of receivers or radiometers 170a, 170b, 170n are used, the assembly of receivers could have a honeycomb appearance. To limit the aperture of each receiver to the microwave radiation from a small patch (pixel) of the sky, a tube 170t (e.g., rectangular, hexagonal, etc.) is placed above each receiver. The inside diameter of the tube and length (assuming the inside of the tube does not reflect Microwave) of the tube determines the field of view (pixel of the sky) that is seen by each receiver element. The rectangular tube can be
15 coated on the inside with known materials so that the inside of the tube will not reflect Microwave.

To allow for the use of a less sensitive receiver, a plurality of tubes can be pointed to one field of view. The microwave signal from all of the tubes could then be combined to form a stronger signal that could be detected by a less sensitive (and perhaps less costly) receiver.

20 Because of the weakness of cosmic background radiation, and attenuation of the microwaves by Earth's atmosphere, in particular the water vapor in the atmosphere, the use of cosmic background microwave will be most effective when the receiver (radiometer) is in a high flying aircraft, HALE craft, or satellite, and the craft being searched for is a high flying stealth aircraft, stealth HALE craft, or stealth satellite.

25 Another background radiation source that can be used is the Earth itself. As mentioned above, the Earth can also be considered a black body, or a gray body, at the temperature of the Earth's surface or about 300 degrees K. For example, an infrared receiver on a detecting craft can look at small areas (pixels) of the ground at sequential times, for detecting the attenuation of the infrared radiation produced by a Stealth Craft obscuring part of the radiation from the ground
30 pixel. Since the wavelength corresponding to 300 degrees K is in the infrared range, the normal microwave stealth techniques do not obscure in this wavelength. The skin temperature of the stealth craft is not likely to closely correspond to the ground temperature of the earth below. Thus, the craft will produce a contrast.

Determination of Distance to Target

As shown in Fig. 13, the well-known method of triangulation or parallax can be used to determine the distance. This method requires two detectors. The Stealth Craft 180s is detected by receiver 180r and by receiver 180q. Since the location of receivers 180r and 180q are known at the time of detection, geometric methods, well known in the art, can be used to calculate the location of Stealth Craft S and the distance to same.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are, therefore, intended to be embraced therein.

The term "comprising", as used herein, shall be interpreted as including, but not limited to inclusion of other elements not inconsistent with the structures and/or functions of the other elements recited.